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BRAZILIAN EVIDENCE ON THE GENESIS OF THE DIAMOND.

THE extensive working of the "dry diggings" of South Africa has thrown a light on the original associates and probable mode of origin of the diamond, which it would be vain to look for in the ordinary type of diamond fields as known in other parts of the world, since all of these, with rare and imperfectly known exceptions, correspond almost exactly with the river washings of the Cape district. The group of mines about Kimberley have shown beyond a doubt that here at least the association of the diamond is with an eruptive rock of ultra basic composition, and, although opinions differ as to the exact mode of origin, all authorities seem to agree on the main fact that in some way this association is a genetic one. To one familiar with the Brazilian diamond fields this conclusion seems a startling one and utterly inapplicable to them. The evidence in its favor, if any exists, is either concealed and has been overlooked, or, as at first sight seems most probable, a totally different association is presented, necessitating the hypothesis of the formation of the mineral under a far wider range of conditions than has been admitted by the students of the Kimberley occurrence. In the present paper it is proposed to discuss the observations, in great part unpublished, that have thus far been made in Brazil bearing upon the question of the genesis of the diamond, with a view of seeing in how far they are in accord, or disaccord, with the much more complete observations in the South African mines.

With two exceptions, which will be more fully discussed below, all the known Brazilian diamond washings are in material — sand and gravel — which has clearly been transported from its place of origin and equally clearly contains the débris of a greater or less variety of rock types, some one or more of which may reasonably be presumed to have a genetic relation to the diamond. As the latter, however, is almost invariably found free in such deposits, or attached to the other elements by a cement, usually limonite, which is visibly of secondary origin, such deposits throw little light on the history of the gem. For the most part these deposits are of quite recent origin, having evidently been formed by the action of the present drainage agencies. In a few cases the gravel has been attributed[1] to the disintegration of conglomerates of various ages, which in one case is presumed to be very great. The age of the gem is thus carried back to a more or less remote geological period, but no other essential addition is made to its history. The concentrates of the rarer and heavier elements of these gravels obtained by the miners in their operations contain many rare and interesting minerals which have attracted the attention of mineralogists, but, thus far, the hopes that have been entertained of tracing the diamond to its original home by means of these satellites, have proved illusive, since none of them have proven to be sufficiently constant to give more than merely presumptive evidence. The few cases that have been reported of diamonds included in other minerals, as iron ores and rarely quartz and anatase, refer to minerals that are known to be readily formed by secondary action, and thus are not necessarily contemporaneous with their inclusions.[2]

The associates of the diamond in these gravels are naturally fragments of all the rocks capable of resisting decay and the

[1] DERBY: Am. Jour. of Sci., 1882, XXIV, p. 34.

[2] The specimen described by Eschwege, who attributed great importance to it (Geognostisches Gemälde, p. 430; Beiträge zur Gebirgskunde Brasiliens, pp. 213 and 341), and which is now in the Heuland collection in the British Museum, is apparently a cleverly executed fraud. The limonite and scorodite of the drusy cavity in which the diamond rests present the peculiar and very characteristic aspect of these minerals

wear of transportation that have contributed to the deposit, together with the isolated minerals derived from the breaking down of these rocks and of such others as have entirely disappeared as rock-masses and are now only represented by the more resistant of their constituents, which have been more or less completely assorted according to their resistance to disintegration and to wear, to their specific gravity and to the size of grain. These isolated minerals, the *formation* of the miners, who attach great importance to them, can in some cases, as of zircon, monazite, xenotime, etc., be referred with tolerable certainty to original eruptive rocks, though they may, and in many cases doubtless have, passed through others before reaching their present place in the gravels; others, as staurolite, disthene, etc., can with equal certainty be referred to metamorphosed clastics, but by far the greater part, as quartz, the iron and titanium oxides, tourmaline, garnet, and many others might be from either eruptives or metamorphosed clastics, or from both. The minerals which can with more or less probability be attributed to eruptive rocks, are not so predominant or so constant in their occurrence that any particular significance can be attached to them. Their evidence, so far as it goes, points rather to the acid eruptives, as granites, etc., than to the ultra basic types of the Kimberley district.

In only one Brazilian mine, so far as known, are basic eruptives a characteristic feature, and in this the conditions are such that the association seems to be accidental rather than genetic. This is the Agua Suja (dirty water) mine in the Bagagem district of western Minas Geraes, which has been excellently studied by Messrs. Gonzaga de Campos, Hussak, and Calogeras,[1] though

from the gold mine of Antonio Pereira, near Ouro Preto, which is the only known Brazilian locality of scorodite, but is not known as a diamond locality. The specimen is reported to come from the Abaieté district to the west of the Sâo Francisco, but no other specimens of scorodite, or of limonite of this character, are known from that region, where, moreover, only gravel deposits had been worked, whereas the specimen in question is evidently from a mine, and not from a deposit of transported material.

[1] GONZAGA DE CAMPOS: Jazidas Diamantiferas de Agua Suja, Rio de Janeiro,

much is yet to be learned regarding this unique deposit. The region is characterized by inclined strata of micaceous schists, in part staurolitic, which are regarded as metamorphosed clastics, with intercalations of amphibolites, which are almost certainly metamorphosed eruptives. This schist series is cut by dikes of granite which, so far as observed, are characterized by muscovite either alone or in association with biotite, and which are generally tourmaliniferous. Quartz veins which frequently carry a little mica are also common. Upon this group of schists and granite rest horizontal beds of soft sandstones, with intercalated layers, or sills, of trap—augite-porphyrite or melaphyre—which are presumably of Triassic age. In the same region, although not definitely known in the immediate vicinity of the mine, there is another obscure eruptive group which has furnished material characterized by grains of pyroxine, perofskite, and magnetite, to beds of clay and impure limestone that overlie the sandstone and trap, and, in places, present something of the aspect of ash-beds or volcanic breccias. This group, though very imperfectly known, is certainly distinct from the traps, and its probable relations will be discussed below.

The diamond-bearing bed of Agua Suja is a thoroughly decomposed conglomerate, or breccia, in which both matrix and the included pebbles are transformed into clay. The original angular outline of the pebbles (or rather bowlders, as they are often of considerable size), can, however, be recognized, as also, in many cases, the type of rock to which they belonged. The various types of the schists and granites upon which the diamantiferous bed rests in part (in part also on sandstone and trap) are recognizable, as well as masses of the sedimentary and later eruptive series. Fragments of opal, which may be of secondary origin, constitute a peculiar feature when this mine is compared with others of the same region (Bagagem) or of the other diamantiferous regions of Brazil. Still more peculiar and

1891. E. HUSSAK: In the above cited pamphlet and in Relatorio da Commissão Exploradora do Planalto, Rio de Janeiro, 1894. J. P. CALOGERAS: Revue Universalle des Mines, XXIX, 1895.

characteristic is the presence in great abundance of magnetite and of a magnetite rock, which Dr. Hussak has succeeded in tracing to a special magnetite-perofskite type found by him near Catalão, in the state of Govaz.[1]

This last element of the diamantiferous bed cannot be referred to any of the known rocks of the region, but it points in the same direction as the above mentioned eruptive elements of the limestone and clay beds that are known to occur in the region and that may be presumed to extend to the immediate vicinity of Agua Suja. These elements, pyroxene, perofskite and magnetite, suggest a type of basic eruptive passing into an iron ore such as has actually been met with in the Jacupiranga district of the state of São Paulo in genetic relations with various nepheline-bearing rocks, the whole constituting a typical volcanic series.[2] As a somewhat similar volcanic center is known at Caldas[3] at no great distance from the Agua Suja region, there is a reasonable probability that another one may exist in the immediate vicinity, and that it may have furnished the problematic material of the diamantiferous bed. This last is not clearly referable to the present drainage conditions of the country and is very likely to prove to be an ancient conglomerate, or breccia, possibly in relation with the eruptive manifestation that is presumed to have contributed to its elements.

The Agua Suja occurrence thus offers a certain number of analogies with those of the Kimberley district which are entirely lacking in the other Brazilian localities, so far as they are known. It is especially to be noted that the absence of these analogies is as conspicuous at the nearest locality, Bagagem, only about twenty miles distant in the same river basin, as at any other. The country rock both at Kimberley and Agua Suja is horizontal, of approximately the same age (late palæozoic or early secondary) and with intercalated sills of trap of very similar character and composition, but which in both cases has no

[1] Neues Jahrbuch, 1894, II, p. 297.

[2] DERBY: Am. Jour. of Sci., XLI, 1891, p. 311.

[3] DERBY: Quart. Jour. of the Geol. Soc., 1887, p. 457.

apparent relation with the occurrence of the diamond; the deposit is conglomeratic, or brecciated, and in both cases the most characteristic elements of the conglomerate represent rocks of an ultra basic type, and in both the diamond is presumed to be an element of the cement rather than of the included pebbles; perofskite and garnet (pyrope) are characteristic accessories (garnets though frequent in most Brazilian sands and gravels are exceptionally rare in those of the diamond washings; those of Agua Suja present the rare cubic habit); the diamonds *seem* to be distributed with a considerable degree of uniformity throughout the mass.

With these analogies are, however, associated differences that are, in appearance at least, of equal if not greater importance. The Agua Suja deposit is a bed, not a volcanic neck; in it clastic elements, of a much more varied character than those of Kimberley greatly predominate over those of eruptive origin, which also are more varied in character; the cement is apparently clastic rather than eruptive; the eruptive elements, exclusive of the trap, probably represent basic phases of the nepheline- or augite-syenite type of rocks and not the peridotitic, and there is as yet no direct evidence that they have anything to do with the diamond; the original matrix of the garnets is unknown and there is no evidence that their association with the diamond and with the basic eruptives is direct and not accidental. If, as is quite within the range of possibilities, eruptive necks of the Kimberley type should be discovered in the Agua Suja region, or contemporaneous (?) sedimentary deposits of the Agua Suja type in the Kimberley district, some of these differences would doubtless become analogies, but that of the *probable* original rock type would still remain and would require an extension of the views at present held regarding the type of eruptive rocks with which the diamond is associated. If, as some hold in regard to the Kimberley occurrence, the diamond is the product of meta morphic action on carbon-bearing rocks and not an element of the eruptive rock itself, this last difference would lose much of its importance. In this case, the Kimberley and Agua Suja

occurrences would fall into line as phases of the same phenomenon of contact metamorphism, and to this it may be added that the, at present, striking differences between the latter and the other known Brazilian occurrences would be reconcilable.

Before leaving the topic of African analogies it may be mentioned that in another Brazilian diamond region, that of the river Abaiete, a porphyritic peridotite (picrite-porphyry) with perofskite, quite similar to that of Kimberley as described by Lewis and others, has been found. Its known occurrence is, however, at some distance from the diamond washings and no relation between the two would ever have been thought of if it had not been for the Kimberley occurrence.

In the oldest and best known of the Brazilian diamond fields, that of Diamantina in Minas Geraes, there is an apparent relation, first noted by Eschwege in 1822 and confirmed by all subsequent writers, between the distribution of the diamond and that of the quartzose rock known as itacolumite. Eschwege who first described this rock[1] recognized a schistose and a massive type, the latter often presenting a conglomeratic appearance and, occasionally, an apparent lack of conformability with the former.[2] As, however, both types, and the schists associated with the schistose one, were considered as constituting a single division of the primitive group and as having a special, and non-clastic, mode of origin, the two were not separated and the question of the conglomeratic character was left by Eschwege as an unsolved problem. The predominance of the massive type of itacolumite in the Diamantina region was noted and from this a genetic relation between the rock and the diamond was inferred, an hypothesis which has become deeply rooted in mineralogical literature. About 1840, and after the publication of Eschwege's various works, diamonds were actually discovered and worked in this rock at Grão Mogol, some 100 miles, more or less, to the northward of Diamantina. The locality was

[1] Geognostisches Gemälde von Brasilien, und wahrscheinliches Muttergestein der Diamanten, Weimar, 1822.

[2] Beiträge zur Gebirgskunde Brasiliens, Berlin, 1832, pp. 210, 216.

visited and minutely described by Helmreichen[1] who confirmed Eschwege's views of the genetic relation of the diamond with itacolumite, although he confessed a doubt as to whether the rock, which had a conglomeratic aspect, might not be of clastic origin. Subtantially the same view was taken by Heusser and Claraz[2] who also visited the locality and who considered itacolumite as a quartzose phase of hornblende-schist and attributed the apparent pebbles of the diamond-bearing bed to concretionary action. In 1882, the present writer showed[3] that in the Diamantina region the massive itacolumite of Eschwege really constitutes an independent formation resting unconformably on the upturned edges of a lower series to which the schistose type belongs, and containing elements derived from it, the diamond being probably one of these derived elements. Several of the "dry diggings" of the vicinity of Diamantina were cited as being probably disintegrated masses of this ancient and metamorphosed conglomerate and the Grão Mogol deposit, which was not seen, was referred to as being presumably another example of the same kind. Professor Gorceix who afterward visited the Grão Mogol locality, and who for the Diamantina and other regions accepted my view of the dual character of itacolumite as originally described, agreed with Helmreichen and Heusser and Claraz in uniting the diamond-bearing bed with the lower schistose itacolumite, but, in opposition to their view, he considered the whole series as clastic.[4] The pebbles, or pebble-like bodies of the old writers, of the diamond-bearing bed were thought to be derived elements, while the mica, pyrite and martite of the same rock were considered as authigenic. The question as to which of these two groups of elements the diamond should be referred was, on theoretic grounds, decided in favor of the latter, a view that was rendered necessary by that

[1] Ueber das Geognostische Vorkommen der Diamanten und ihre Gewinnungsmethoden auf der Serra do Grâo-Mogor. Vienna, 1846.

[2] Zeitschrift d. deutsch. geol. Gesellschaft, XI, 1859, p. 448; Petermann's Mitth., 1859, p. 447.

[3] Am. Jour. of Sci., 1882, XXIII, p. 97; XXIV, p. 34.

[4] Bulletin de la Societé Géologique de France, XII, 1884, p. 538.

of the unity of the formation, since elsewhere the diamond was considered to be authigenic under different conditions in a different rock referred to the same geological series.

The question of the unity of the section at Grão Mogol and of the clastic origin of at least the upper portion to which, according to all authorities, the diamond is confined, is an important one in this connection, since, if Gorceix's view is correct, it involves that of two widely different modes of genesis for the diamond in the same field. Not having seen the place, it is with considerable diffidence that I venture to contest the views of the eminent authorities who have.

The accompanying figure, reproduced from one of Helmreichen's sketches, gives what seems to me to be a more accurate

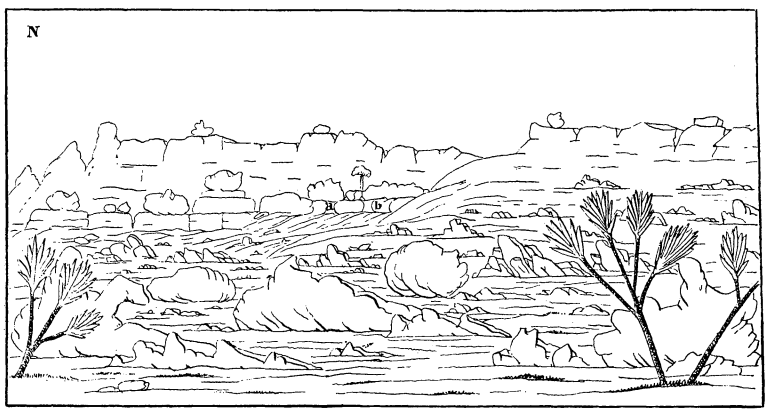

FIG. 1.—Left bank of Corrego dos Bois, near Grão Mogol showing diamond-bearing bed (*a*, *b*). After Helmreichen.

representation of the actual aspect of the exposure than the somewhat diagrammatic section given by Gorceix, and it has the further element of authenticity of representing, at the base of the diamond-bearing bed (*a*, *b*), an apparent unconformability that is not in accord with the theoretic views of the author of the sketch. Numerous cases of a break in the succession have, on close examination, been observed in the Diamantina district that are much less apparent in the topographical features than

the one presumed to be here represented. The two rocks are often found united in the same rock-mass in such an intimate manner that, given the almost perfect identity in aspect and character, one is frequently inclined to doubt the evidence of his senses even after unequivocal proofs of the existence of a break have been detected. Similar cases of a complete blending of his massive and schistose types are graphically represented in other sketches given by Helmreichen which can best be interpreted on the hypothesis of an unconformability. In the present case, it seems to me that, admitting the accuracy of this sketch, the appearance of a break is so evident that before rejecting it most geologists would require much stronger evidence than has yet been presented.

A recent examination of a specimen with an inclosed diamond in the collection of the National Museum at Rio de Janeiro shows that the Grão Mogol rock contains both authigenic and allothigenic elements to either of which groups, leaving out of account considerations derived from other points, the diamond might with equal plausibility be referred. The predominant element quartz,which is presumably allothigenic, has by recrystallization, secondary enlargement, or other process, taken on the aspect of an authigenic element. The mica-like mineral (apparently a clintonite) and the iron minerals, pyrite and martite (magnetite?) are certainly authigenic. Allothigenic elements are represented (leaving out of account the pebbles which are not well defined in the specimen in question) by distinctly rolled zircons. Specimens of typical *schistose* itacolumite, which though not from Grão Mogol may be taken as representing the supposed lower series of that place, present the same mixture of authigenic and allothigenic elements (the latter represented by well rolled zircons) and therefore the same evidence of clastic origin.

As the case stands at present, the evidence from Grão Mogol regarding the genesis of the diamond is inconclusive. The rock, whether one or two series are represented, is a metamorphosed clastic and no decisive evidence can be presented to place the diamond in the class of either the authigenic or allothigenic ele-

ments of this rock. If it belongs to the former class, two modes of genesis must be admitted in the same field in order to reconcile the occurrence with that at São João da Chapada ; if to the latter, the two occurrences can be explained on the hypothesis of a single mode of genesis, but, in case the series proves to be a single one, two periods of formation must be admitted.

For the question of genesis the most significant of the Brazilian localities is that of São João da Chapada near Diamantina

FIG. 2.— Diamond mine at São João de Chapada. The view is looking northward into the Barro mine, which runs into the Duro under the footbridge. The diamond-bearing layers dip into the bank at the right at an angle of about 50°. The open space in the foreground where the wash-house, concentration tanks (*canoas*), and heaps of diamond-bearing earth are located, represent the excavated portion of the left bank containing the upward prolongation of the diamantiferous layers. The wide trench near the pump-house at the left is apparently on the outcrop of one of the layers.

which has never been satisfactorily studied and described. The accompanying view, drawn from a photograph, which is also reproduced in Boutan's monograph on the Diamond in Fremy's *Enclyclopedie Chimique*, shows its character as a great gash resembling a railroad cutting across the crest of a high ridge that forms part of the divide between the waters of the Jequitinhonha and

the São Francisco. Two mines, the Barro (clay) and the Duro (hard), opened on opposite sides of the ridge have come together in the center (the footbridge in the middle ground of the view marks the division) so as to form a continuous cutting nearly 500^{m} long with about 40^{m} of maximum depth. The Barro mine drains to the São Francisco through the Rio Pardo, an affluent of the Rio das Velhas, the Duro to the Jequitinhonha through the Caethé-merim. Both the Pardo and the Caethé-merim, but particularly the latter, are famous diamond streams.

The material exposed in the mines is a soft, soapy clay that is graphically described by Burton[1] as follows. "The material is a hardened paste of clay, whose regular and level stratification argues it to have been deposited in shallow water. The eastern side of the gap is the more ferruginous formation (terra vermelha); on the west it is mixed with beds of white sand. Below one foot of brown soil the argillaceous matter has the usual staining and marbling, glaring white like fuller's earth, with feldspar and kaolin, chocolate-brown or rape-colored with organic matter, blue-green with traces of copper [?], pink and rose purple, and dark yellow with various oxides of iron, especially hematite, and dark steel color with oxide of manganese[?]."

In the whole extension of this immense cutting, nothing approaching the gravel, the usual characteristic of a diamond mine, is to be seen and, with the exception of quartz veins, it is difficult to find a specimen that will resist the pressure of the fingers. The structure as exposed on the sides of the cutting, is much obscured by slides and weather action, and Burton's mistake of horizontal stratification and other indications of a shallow water deposit (thus corresponding, except in the character of the material with the other diamond deposits of the region and with the preconceived ideas of his informants, the miners) was a natural one on the part of a non-geological observer. The true nature of the clay as a decomposition product of schistose rocks had already been clearly recognized by Heusser and Claraz, who first described the mine and who iden-

[1] The Highlands of the Brazil, London, 1869, II, p. 129.

tified the original rock type as hornblende-schist,[1] giving the impression that the diamond occurred throughout the whole mass. The limitation of the diamond to certain streaks, or layers, was recognized by Burton, who gives the following excellent description of them.

"The richest lode (*corpo*) is No. 3, or the highest. The strike of the ribboned clays is north and south, bending [dipping] eastward. The lode inclines towards the higher grounds, and thus the owner hopes to find the gem-bearing strata spreading over the crest or watershed ridge which forms his property. Through the ferruginous sandstone (*borra*) and the white feldspathic matter run dikes and lines of fragmentary rock crystal, sometimes fibrous like arragonite, and often finely comminuted. Large pieces of imperfect specular iron and thin strata of quartz, yellow and brown at the junction, thread the argile, and I was shown a specimen of fine sandy conglomerate, blackened and scorified by the injection of melted matter.[2] The characteristics of this upper lode are a dryer clay, silica, a trace of copper [a green silicate of the nature of chlorite or serpentine?], of iron cement, and of Canga in small pieces; when the specular iron is in large pieces and abundant the rock is rich in gems. Its 'agulhas' [rutile] are iron-like bundles of needles welded together by intense heat; some are double, the fibers coming at obtuse angles. The 'Agulhas Cor de Ouro' have a burnished coppery surface, whence the name. Throughout all these corpos the diamonds are small, averaging perhaps a little under one grain or 64–72 per oitava; they are mostly crusted superficially

[1] Although Rose failed to find hornblende in the material submitted to him by Heusser and Claraz, it is possible that this idea was not entirely without foundation. Throughout the whole region traversed by them, intercalations and dikes of amphibolic and pyroxenic rocks are frequent in the schist series and generally they are the only ones of the not distinctly quartzose rocks whose original composition can be readily determined. As they usually give green decomposition products the staining referred by Burton to copper may, with considerable plausibility, be attributed to them. To judge from other exposures, the absence rather than the presence of such rocks at São João da Chapada would be a motive for remark.

[2] Probably a "Canga" or mass of sand or clay cemented by limonite common in such deposits.

with a light green tinge. Lower down we came to the middle or second body. Here the 'tauá' (feldspathic clay) was stiff and sandy, marbled with a fat, blue, muddy marl, which leaves upon the fingers a greasy, steely streak. It also yields a dark olive-green argile harder than the rest; like all the others it has consistence in situ, but when removed it crumbles to pieces after drying. Lieutenant-Colonel Brant gave me from this corpo a fragment of hard, large-grained clay, reddish colored with oxide, and showing a small brilliant imbedded in it. We then descended to the lowest formation. Here the clay contains very little sand, and much stained; the colors are white and blue, red and yellow, rosy, spotty, and in places dyed as with blood. Here also are found the 'Agulhas' in streaky bundles of iron-like asbestos. The sole of the pit is uneven with working, and in places 'horses,' 'old men,' and long walls of stiff clay have been left standing amongst the holes and gashes. From this point the several lodes are distinctly traceable in the walls of the basin." A more technical description is given by Gorceix[1] as follows: "One of the beds of bluish black color is composed of clay impregnated with oligiste in small fragments with rutile and anatase; the second of lithomarge with entire crystals of quartz having the same aspect as those of the topaz mines [near Ouro Preto]; the third and most important, with a thickness of more than 1.50^{m}, is composed of a series of beds of mottled clay. The stratification planes, parallel to those of the quartzites, are still clearly visible; the layers are undulated, folded like those of the intact schists that are found a few meters distant. Fragments of schist still almost intact occur in the midst of the clay. These beds of clay are traversed by small veins of quartz, granular or in bipyramidal crystals, oligiste and rutile, showing no signs of wear. Octahedral oligiste is found in certain points in extreme abundance impregnating the rock; in other points it is substituted by ordinary oligiste. The aspect of the gravel resulting from the washing of this clay is entirely different from that of the alluvial deposits, though composed of the same elements. The

[1] Comptes Rendus, 1881.

diamonds themselves of this region are easily distinguished from those of the rolled deposits by their rugose faces, sharp angles, and superficial greenish blue coloration."

On the occasion of my visit in 1881 only fallen masses that appear to represent the bodies 3 and 2 of the above description were to be seen, the operations of the mine being at that time suspended. One of these masses was so evidently a section of a vein that the conclusion was announced[1] that at São João da Chapada the diamond is a vein mineral accompanying quartz and an argillaceous rock of indeterminable character in the series of metamorphic schists. This conclusion was subsequently fully confirmed by Gorceix as the result of prolonged prospecting operations,[2] and thus one mode of occurrence of the diamond in the matrix was clearly established which, in appearance at least, is widely different from that at Gão Mogol and at Kimberley.

In the various papers by Gorceix and myself the schistose series of the gold and diamond region of Minas Geraes, in which the diamond occurs at São João da Chapada, is assumed to consist essentially of metamorphosed clastics, though no direct proof of this assumption is given. As regards the diamond-bearing layers, they are called veins, but no definite opinion regarding their mode of origin is expressed. For the question of the genesis of the diamond both these points are important.

All writers on the geology of this region are agreed that the characteristic formation is a great series of phyllites, quartz schists (itacolumite), iron-mica schists (itabirite), and limestone, and that this series constitutes a geological unit. This last point is assumed rather than proven, since there may be a break in the succession which has thus far escaped observation, just as that above indicated between the upper and the lower itacolumite was overlooked, or disregarded, by the older writers. For the purposes of the present discussion, however, it is of little conse-

[1] Am. Jour. Sci., 1882, Vol. XXIII, p. 97.

[2] Comptes Rendus, No. 25, 1881. Am. Jour. Sci., 1882, Vol. XXIII, p. 97, and Vol. XXIV, p. 34.

quence whether the series as here limited by the exclusion of the massive itacolumite of Eschwege is a simple or a composite one, since the evidence as to origin applies very directly to the beds in question exposed in the diamond mine itself.

As recent studies in various parts of the world on schists of doubtful character have proved that the schistose structure is not, as was long supposed, an unequivocal proof of a clastic origin, an attempt has recently been made to find in the rocks themselves internal evidence for or against the hypothesis of such an origin. As is well known, most of the mineralogical elements of a metamorphosed rock, whether clastic or otherwise, are authigenic; others which in certain cases may be presumed to be allothigenic may have been broken up, recrystallized, enlarged by secondary additions,[1] or etched, so that all traces of the original worn surface of clastic grains may have been lost or so obscured as not to be recognizable with certainty. The hopes of finding such internal evidence are therefore limited to the rare accessories, and among these practically to zircon, not only on account of its almost universal distribution in sedimentary deposits, but also of its resistance to chemical changes. In the examination of the heavy residues of a considerable number of the rocks of the series in question, it was found that in rocks of their character and degree of metamorphism, zircon is the only element that can be depended upon to give unequivocal evidence as to the mode of origin. All the other constituents, principal or accessory (quartz, mica, iron, and titanium oxides, tourmaline, disthene, etc.), present the fresh appearance of authigenic elements, as most of them doubtless are, though in some cases this appearance may be due to the fragmentation, regeneration, or etching of original clastic grains. On the contrary, the zircons in the considerable number of residues examined have failed to show evidence of secondary modification by any of the processes

[1] As will be shown elsewhere, tourmaline may be regenerated by secondary enlargement in the same manner as in the well-known case of quartz. A remarkably fresh appearance of the surfaces of quartz grains, due to etching, is noticeable in the washings from the clays of São João da Chapada, but it is to be presumed that this is a phenomenon of decomposition rather than of metamorphism.

mentioned so that, when present, their evidence is positive when they show distinct signs of wear, doubtful when these signs are absent or dubious.[1]

Applying the zircon test to the material at hand from the São João da Chapada mine the evidence for the clastic origin of the greater part of the original rock types from which the clays are derived has proved to be unexpectedly satisfactory. A number of samples of typical clays, including some reputed to be diamantiferous, afforded zircons which in abundance, size, and amount of wear, are comparable with those of the granular quartz rock (itacolumite) that occurs above the schists in the immediate vicinity of the mine. To judge from the number and character of the zircons, these samples represent original grits rather than more purely argillaceous material as was supposed from their present character and appearance. This conclusion is confirmed by the amount and size of the quartz grains (beautifully etched) that are also separated by the washing of the clay. In a miner's concentrate representing mixed material, fresh, prismatic glassy zircons occur mingled with the ordinary rounded, reddish clastic type indicating that other types of rock, presumably eruptive, may be represented among the clays. For the present discussion, however, the essential point is that the generality of the zircons of the clays are worn, thus confirming the assumption, based on stratigraphical evidence, that the clays of the mine represent a series of schists of which the predominant types are of clastic origin. This conclusion, however, does not exclude the possibility of subordinate intercalations,

[1] The rounding of the angles alone cannot be taken as an unequivocal sign of wear, as it is often an original feature of the zircons of undoubted eruptive rocks. When the angles are rounded by attrition the faces are also dulled in a manner that is readily distinguishable from that produced by malaconization. Undoubted clastics occur in which the signs of wear of the zircons are inappreciable, either because the amount of transportation has been too small or the material too fine to produce them, or because they have been involved in other elements, as in the case of arkose and tuffs. In the case of argillaceous rocks the rarity and minuteness of the zircons may be an argument in favor of a clastic origin even when they show no distinct signs of wear, but the evidence is not conclusive as they are minute and rare in some eruptives as well.

or injections, of eruptive origin, which, judging from evidence elsewhere, are rather to be expected than otherwise in a cutting like that of São João da Chapada. For the question of the genesis of the diamond this hypothesis is of prime importance and the evidence thus far available for or against it will now be examined.

Of the three diamond-bearing bodies described by Burton and Gorceix only two were seen by me. The masses shown me were displaced by landslides, but, as nearly as can be determined, they represent the middle and lower bodies of Burton.

The mass supposed to represent the lower body of Burton and the mottled clay of Gorciex consisted of a considerable rectangular block of quartz, with plates of specular iron, and with laminated clay representing the decomposed country rock adhering to it on one side. On the other side was a mass of friable structureless reddish clay, sharply defined on the side opposite the quartz from the harder laminated clay of the decomposed country rock, which is here also reddish, but of a different tint and aspect. The whole appearance of the mass was that of a vein with sharply defined walls, and it was so described on account of the quartz, though, as the earthy portion was referred to a decomposed rock of undetermined character, the term dike might have been employed with equal propriety. The earthy diamond-bearing mass was shown to consist of an argillaceous portion stained with iron oxide and a sandy portion with quartz and tourmaline. The heavy residue which has since been separated and examined consists principally of aggregations of specular iron and of a micaceous mineral representing some altered silicate with a great abundance of microscopic brown tourmaline. Yellowish, burr-like aggregates of anatase are also abundant, while rutile is comparatively rare, as are also grains of disthene. All of these minerals are evidently authigenic. The rare grains of zircon are in part distinctly worn, in part with the fresh appearance of an authigenic element. A few grains of staurolite also occur, and these are, for the most part, rounded, giving them a worn appearance,

but as some of them are distinctly etched, it is thought that this aspect may be due to etching rather than to attrition. Unfortunately, it is not absolutely certain that the zircon and staurolite may not have been introduced from a foreign source, as at the time the washing was made the extreme care now found necessary to avoid admixture was not observed. On the assumption that the residue is a pure one (as it is believed to be),[1] the interpretation would be that the original vein material contained primary tourmaline and zircon with iron and titanium minerals that have furnished material for secondary hematite, anatase, and rutile, and that the accompanying schist contained clastic zircons, staurolite that is authigenic if the rounding of the grains can be attributed exclusively to etching, and disthene. The hypothesis that best suits these conditions is that of a granitic (pegmatitic) vein accompanied by phenomena of contact metamorphism.

The mass that was shown to me as representing the Barro Preto (black clay, middle body of Burton) had the characteristic of a bed rather than of a vein. The clay is well laminated, ribboned with fine regular alternating streaks of white and black, the latter composed mainly of a fine powder of hematite. The residue, freed from clay, shows a great abundance of black hematite, so finely divided that much of it floats away in the washing, a moderate amount of etched quartz, a small amount of tourmaline in coarser grains than in the body above described, and a comparative abundance of rolled zircons, which appear also to have been somewhat malaconized. The titanium minerals, rutile and anatase, are absent, or extremely rare. A sample subsequently received as representing the same body agrees substantially with the above, except in the greater abundance of quartz and the absence of tourmaline. All these indi-

[1] In the case of an admixture, rounded staurolites and fresh disthenes are not the minerals that might be expected to be introduced in the residue through lack of care in the preparation. Two or three grains of monazite were found that were certainly introduced by accident, but this very circumstance gives confidence in the general purity of the residue, as the much more abundant disthene and staurolite are not its usual associates.

cations point to an original bed of sandy ferruginous shale rather than to a vein.

The third body, not seen by me, is, according to both Burton and Grociex, characterized by a white feldspathic clay, kaolin, or lithomarge, with crystals of quartz and specular iron. Specimens exactly corresponding to this description were kindly furnished by Dr. Thomassi Bezzi, who collected them with the assistance of the owner of the mine, so that their authenticity is undoubted. Two specimens representing the Barro and the Duro mines are practically identical. In both a mass of snow-white, structureless clay, with nests of quartz crystals and specular iron, has adhering to it colored laminated clays. The contact between the two, sharply defined by the strongly contrasted coloration, is in part linear, in part irregularly undulated, but without appearance of graduation from one to the other. Irregular stringers of the white clay penetrate the mass of the colored, and irregular masses of the latter are inclosed on the former. The whole appearance of the contact is that of a vein or dike, represented by the white clay, with stringers and inclusions of the country rock. The contrast between the heavy residues of the two kinds of clay is as striking as that of their coloration and general appearance. Corresponding quantities taken at a distance of a few millimeters from each other or either side of the contact gave very different residues, both as regards quantity and mineral composition. That of the white clay is extremely small, consisting, aside from rare grains of quartz and specular iron that apparently come from segregations rather than from the body of the clay, exclusively of delicate needles of yellow rutile, the *Agulhas cor de ouro* (golden needles) mentioned by Burton. The residue from the colored clay is, on the contrary, abundant, consisting, after the separation of the quartz (beautifully etched) and iron oxide, of rolled zircons, anatase, tourmaline, and iron-stained earthy grains of rudely prismatic form that evidently represent a decomposed silicate, possibly staurolite. This last is a characteristic residue of a metamorphosed clastic rock, and as tourmaline and anatase seem to be

present in abnormal abundance, contact metamorphism is strongly suggested. The residue of the white clay, on the other hand, gives no indication as to its origin, since the only characteristic accessory found in the small quantity available for washing is rutile, which is so widespread and varied in its mode of occurrence and association as to be indeterminative. One of the washings from the colored clay gave two types of zircons, the usual round, much worn reddish ones, and less worn whitish elongated prisms. The latter resemble those already mentioned as occurring (with a fresher appearance, however,) in a miner's concentrate, and still more closely those of a partially decomposed rock from the Sopa mine in the neighborhood (where lithomarge also occurs, but is not known to be diamantiferous), which strongly resembles the European "porphyroid," and is either metamorphosed arkose or porphyry, probably the former.

This white clay, in the character of its material and of its contacts, and in the lack of characteristic clastic elements, is strongly suggestive of the so-called pegmatite veins that are of frequent occurrence in similar formations and under similar conditions. The quartzose character of some of the veins, or parts of veins, is not inconsistent with this hypothesis, as the intimate relations and interdependence of quartz and pegmatite veins are well known. The indications furnished by this body are therefore in accord with those of No. 1—that is to say, that the vein matter was probably originally pegmatitic, and that it was accompanied by phenomena of contact metamorphism.

So far as can be made out from the observations thus far made on material the most unsatisfactory that can be imagined (foliated and highly modified by dynamometamorphism and afterwards totally decomposed so as to present, in its present state, one of the most intricate problems of mud geology), the most plausible hypothesis as regards the various clays of the São João da Chapada mine is that they represent an original group of phyllites of varied character, but principally, if not exclusively, of clastic origin, threaded with veins of pegmatite.

The possibility of an admixture of originally eruptive elements in the phyllites themselves is, as already noted, suggested by the supposed copper staining of Burton and also by the harder olive-green clay that he mentions as occurring with the second body. The only rock specimen that has come to hand from the mine is a small fragment of a sericitic schist that, aside from a very fine dust of hematite, gives no residue whatever, and which may be suspected to be a metamorphosed eruptive.

On the hypothesis of the original essentially pegmatitic character of the diamond-bearing bodies of São João da Chapada three important questions arise which can only be solved hypothetically. What was the original type of the pegmatite? Is it eruptive or secretionary? Do the diamonds belong to it or to the country rock in its immediate vicinity, and perhaps modified by it, or to both?

Bodies of pegmatite are quite common in the older rocks of Brazil, both in the diamond regions and elsewhere, occurring not only in the gneiss and granite, but in the schistose series as well. Those that have been examined are dike-like in their mode of occurrence and granitic in composition. They are almost universally decomposed, affording a pulverulent kaolin, not the indurated type of lithomarge. Their residues are usually abundant and typically granitic, representing more particularly the type of the muscovite granites, consisting of zircon, monazite, and almost invariably xenotime. All of these characteristics (which, however, may not be essential) are lacking in the supposed pegmatitic clay of São João da Chapada, in which only the presence of quartz is suggestive of granite affiliation. On the other hand, however, they are compared with great propriety by Gorceix with the topaz-bearing clays of Ouro Preto, and topaz is generally regarded as a granitic mineral. Topaz has not been reported from São João da Chapada, but in one washing from a mixed sample of the clays a minute grain was observed that in form, optical properties, and specific gravity seems to agree with that mineral. The other known types of pegmatite — those affiliated with syenites, diorites, and gabbros

— have not as yet been definitely identified in Brazil, though they doubtless occur. The apparent absence (or extreme rarity) of zircon may perhaps be taken as indicative of gabbro, and considerable masses of this type of rock, to which the supposed pegmatite might be referred as apophyses, are known to occur in the diamond region. So far as known, however, this is the utmost limit in the direction of basic rock types to which one can go, even hypothetically, in seeking the probable original type of this supposed pegmatite.

The question of the eruptive or secretionary origin of pegmatites has long been a subject of discussion among geologists, and eminent authorities can be cited in favor of either view. The recent studies of Lehmann, Brögger, Williams, Crosby, and others seem to have clearly established that most if not all of them are essentially eruptive masses, though possibly modified in some way by aqueous agencies. Even before becoming acquainted with the literature of the subject this view had seemed to me to be the only acceptable one as regards the typical pegmatites of Brazil. The extension of it to such problematic occurrences as the diamond-bearing bodies of São João da Chapada and the topaz-bearing bodies of Ouro Preto cannot as yet be fully established on account of the lack of complete studies in the field and the decomposed condition of the material. Aside from the general analogy that they present with typical pegmatites, nearly all the criteria given in the recent papers by Williams and Crosby and Fuller in support of the hypothesis of eruptive origin can be cited in favor of the same hypothesis as applied to these bodies. If, as is suspected, they present phenomena of contact metamorphism, a crucial test can be applied through the study of the heavy residues of the enclosing schists at different distances from the contact. This, however, involves field studies that for the present cannot be undertaken. As the case stands at present the hypothesis of an eruptive origin, though not fully proven, is by far the most probable.

The response to the third question is still more unsatisfac-

tory than those to the other two. At the time of Burton's visit the most typical pegmatitic body was regarded as the richest of the Duro mine and in his description of the Barro mine he states that the white clay (called *diz*, or chalk, by the miners) served as a guide to the diamond formation. It is by no means certain, however, that the diamonds actually occurred in it rather than in the adjacent colored clays in contact with it and for which it serves as the most apparent guide. In the specimens at hand the part considered as the contact zone is mineralogically the richest, and it may be suspected that the diamonds occur in it rather than in the white clay. The lower body reputed to be the richest at the time of Gorceix's visit is, according to his description and that of Burton, much less decidedly pegmatitic in aspect and the part seen by me seemed to be a decomposed dike with no apparent suggestion of pegmatite. The part of this body indicated to me as diamantiferous belongs certainly to the supposed dike and not to the contact zone. The other body, the Barro Preto, seems, according to the descriptions and the part seen by me, to be a specialized layer of the phyllites the relations of which to the pegmatites (if it has any) are not clear. In short the question as to whether the diamond occurs at São João da Chapada exclusively in the supposed pegmatitic bodies, in the contact zone of said bodies, in layers of the phyllites more or less removed from such contact zones, or in all, must remain an open one.

As the case stands at present the indications seem to be rather in favor of the hypothesis of the formation of the diamond in the phyllites, the presumptive agent being the supposed eruptive which in some of its phases presents a pegmatitic character. This involves, presumably though perhaps not necessarily, the supply of the necessary carbon from the phyllites themselves, but as the series is known to include in many places graphitic members such a supply may reasonably be predicted at São João da Chapada. Moreover the evidence from Kimberley, where, according to Launay (*Les Diamants du Cap*), the rock considered rich only yields one part of diamond to 3 mil-

.ion to 36 million parts of rock, indicates that the amount required is so infinitely small that few rocks can be conceived that may not contain, in some form, the necessary supply of carbon. The amount of this element that presents itself in the form of carbonates in the decay of many rocks, that in their sound condition are not recognized as containing it in any form, is far in excess of that here indicated as necessary. In this connection it may be remarked that the hypothesis that attributes a preponderant importance in the genesis of the diamond to the carbonaceous shales of the upper part of the Kimberley section, is subject to the criticism of furnishing a preposterously enormous superabundance of raw material.

The three localities above discussed offer no certain indications of more than one mode of genesis of the diamond in Brazil. The occurrences at Grão Mogol and Sãn João da Chapada can very easily be brought into line on the hypothesis, which has much in its favor that at the former place the diamond is an allothigenic mineral derived from deposits similar to those at the latter. For São João da Chapada and Agua Suja the comparison presents no difficulty if the diamonds at the last place are assumed to come, as is quite possible, from the underlying schists. If, however, they are genetically related to the later eruptive series, the hypothesis of a substantially similar mode of genesis requires that the predominant factor be an eruptive rock, which may vary greatly in its mineralogical character and mode of occurrence.

As compared with the Kimberley occurrence that of São João da Chapada seems at first sight to be characterized by an almost absolute lack of analogies. Until quite recently the only known feature at Kimberley offering some remote resemblance to the Brazilian fields was the presence of a quartzite in the lower part of the section. This resemblance is somewhat increased by the later developments as metamorphic schists appear mingled with the quartzite in the lower levels of the deep shaft (see section on p. 137 of Launay's *Les Diamants du Cap*). For the present the information regarding these lower

rocks is very meager, and further developments must be awaited to determine whether or not this resemblance has any special significance. Another point in common that may prove to be of greater significance than at first sight appears is the occurrence mentioned by Carvill Lewis[1] of tourmaline and disthene which seem to be formed by metamorphic action about inclosed fragments of schist. It is true that disthene is not a specially characteristic mineral at São João da Chapada, but it is extremely widespread and abundant in the schist series in which the mine is excavated, and of the aluminous silicates, is the most constant and characteristic of the associates of the diamond in the Brazilian alluvial washings. The significance, if any, of its persistent association with the diamond (now verified at Kimberley) is that of a mineral characteristic of the metamorphism (by contact or otherwise) of argillaceous rocks.

In order to bring the Kimberley and Brazilian mode of occurrence into line as phases of a single mode of genesis, it seems necessary to put aside the idea that the recent interesting experiments on the artificial production of the diamond afford a solution of its terrestrial origin, and that the Kimberley type of rock and mode of occurrence are essential features. Presumably also the genesis must be sought in the rocks affected by the eruptive masses rather than in those masses themselves. There are still many obscure points about both places, and until these are cleared up no satisfactory comparison can be made. At São João da Chapada there is little prospect of working being resumed so that no additional light is to be expected from there, but at Kimberley the workings may ultimately reach a depth that will give a complete solution of the problem for that place and mode of occurrence. When this occurs, if it is verified that the ultra basic type of eruptive rock, brecciated structure, and slot-like mode of occurrence are necessary features, the Brazilian occurrences must be put into another category.

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SÃO PAULO, November 29, 1897.

[1] Papers and notes on the genesis of the diamond.